

November 26, 1874.

W. SPOTTISWOODE, M.A., Treasurer and Vice-President, in the Chair.

In pursuance of the Statutes, notice was given from the Chair of the ensuing Anniversary Meeting, and the list of Officers and Council proposed for election was read as follows :—

President.—Joseph Dalton Hooker, C.B., M.D., D.C.L., LL.D.

Treasurer.—William Spottiswoode, M.A., LL.D.

Secretaries.— { Prof. George Gabriel Stokes, M.A., D.C.L., LL.D.
 { Prof. Thomas Henry Huxley, LL.D., Ph.D.

Foreign Secretary.—Prof. Alexander William Williamson, Ph.D.

Other Members of the Council.—Prof. J. Couch Adams, LL.D.; the Duke of Devonshire, K.G., D.C.L.; Capt. Frederick J. O. Evans, R.N., C.B.; John Evans, Pres. G.S., F.S.A.; Albert C. L. G. Günther, M.A., M.D.; Daniel Hanbury, Treas. L.S.; Sir John Hawkshaw, Knt., M.I.C.E.; Joseph Norman Lockyer, F.R.A.S.; Robert Mallet, C.E., M.R.I.A.; Nevil Story Maskelyne, M.A.; C. Watkins Merrifield, Hon. Sec. I.N.A.; Prof. Edmund A. Parkes, M.D.; Right Hon. Lyon Playfair, C.B., LL.D.; Andrew Crombie Ramsay, LL.D.; Major-Gen. Sir H. C. Rawlinson, K.C.B.; J. S. Burdon Sanderson, M.D.

The Presents received were laid on the table, and thanks ordered for them.

The following Paper was read :—

“ Preliminary Notes on the Nature of the Sea-bottom procured by the Soundings of H.M.S. ‘ Challenger ’ during her Cruise in the ‘ Southern Sea ’ in the early part of the year 1874.” By Professor C. WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff on Board. Received Nov. 12, 1874.

[Plates I.—IV.]

During our southern cruise the sounding-lead brought up five absolutely distinct kinds of sea-bottom, without taking into account the rock and detritus of shallow soundings in the neighbourhood of land. Our first two soundings in 98 and 150 fathoms, on the 17th and 18th of December, were in the region of the Agulhas current. These soundings would have been naturally logged “ greenish sand ; ” but on examining the sandy particles with the microscope, they were found to consist almost without exception of the casts of Foraminifera in one of the complex silicates of alumina, iron, and potash, probably some form of glauconite.

The genera principally represented by these casts were *Miliola*, *Biloculina*, *Uvigerina*, *Planorbulina*, *Rotalia*, *Textularia*, *Bulimina*, and *Nummulina*; *Globigerina*, *Orbulina*, and *Pulvinulina* were present, but not nearly in so great abundance. There were very few Foraminifera on the surface of the sea at the time. This kind of bottom has been met with once or twice before; but it is evidently exceptional, depending upon some peculiar local conditions.

From the Cape, as far south as our station in lat. $46^{\circ} 16'$, we found no depth greater than 1900 fathoms, and the bottom was, in every case, "*Globigerina*-ooze;" that is to say, it consisted of little else than the shells of *Globigerina*, whole, or more or less broken up, with a small proportion of the shells of *Pulvinulina* and of *Orbulina*, and the spines and tests of Radiolarians and fragments of the spicules of Sponges.

Since the time of our departure, Mr. Murray has been paying the closest attention to the question of the origin of this calcareous formation, which is of so great interest and importance on account of its anomalous character and its enormous extension. Very early in the voyage, he formed the opinion that all the organisms entering into its composition at the bottom are dead, and that all of them live abundantly at the surface and at intermediate depths, over the *Globigerina*-ooze area, the ooze being formed by the subsiding of these shells to the bottom after death.

This is by no means a new view. It was advocated by the late Professor Bailey, of West Point, shortly after the discovery, by means of Lieutenant Brooke's ingenious sounding-instrument, that such a formation had a wide extension in the Atlantic. Johannes Mueller, Count Pourtales, Krohn, and Max-Schultze observed *Globigerina* and *Orbulina* living on the surface; and Ernst Haeckel, in his important work upon the Radiolaria, remarks "that we often find upon, and carried along by the floating pieces of sea-weed which are so frequently met with in all seas, Foraminifera as well as other animal forms which habitually live at the bottom. However, setting aside these accidental instances, certain Foraminifera, particularly in their younger stages, occur in some localities so constantly, and in such numbers, floating on the surface of the sea, that the suspicion seems justifiable that they possess, at all events at a certain period of their existence, a pelagic mode of life, differing in this respect from most of the remainder of their class. Thus Müller often found in the contents of the surface-net off the coast of France, the young of *Rotalia*, but more particularly *Globigerina* and *Orbulina*, the two latter frequently covered with fine calcareous tubes, prolongations of the borders of the fine pores through which the pseudopodia protrude through the shell. I took similar *Globigerina* and *Orbulina* almost daily in a fine net at Messina, often in great numbers, particularly in February. Often the shell was covered with a whole forest of extremely long and delicate calcareous tubes projecting from all sides, and probably contributing essentially to enable these little animals to float below the surface

of the water by greatly increasing their surface, and consequently their friction against the water, and rendering it more difficult for them to sink”*. In 1865 and 1866 two papers were read by Major Owen, F.L.S., before the Linnean Society, “On the Surface-fauna of Mid Ocean.” In these communications the author stated that he had taken foraminifera of the genera *Globigerina* and *Pulvinulina* living, in the tow-net on the surface, at many stations in the Indian and Atlantic Oceans. He described the special forms of these genera which were most common, and gave an interesting account of their habits, proposing for a family which should include *Globigerina*, with *Orbulina* as a sub-genus, and *Pulvinulina*, the name Colymbitæ, from the circumstance that, like the Radiolaria, these Foraminifera are found on the surface after sunset, “diving” to some depth beneath it during the heat of the day. Our colleague, Mr. Gwyn Jeffreys, chiefly on the strength of Major Owen’s papers, maintained that certain Foraminifera were surface-animals, in opposition to Dr. Carpenter and myself†. I had formed and expressed a very strong opinion on the matter. It seemed to me that the evidence was conclusive that the Foraminifera which formed the *Globigerina*-ooze lived on the bottom, and that the occurrence of individuals on the surface was accidental and exceptional; but after going into the thing carefully, and considering the mass of evidence which has been accumulated by Mr. Murray, I now admit that I was in error; and I agree with him that it may be taken as proved, that all the materials of such deposits (with the exception of course of the remains of animals which we now know to live at the bottom at all depths, and which occur in the deposit as foreign bodies) are derived from the surface.

Mr. Murray has combined with a careful examination of the soundings, a constant use of the tow-net, usually at the surface, but also at depths from ten to one hundred fathoms; and he finds the closest relation to exist between the surface-fauna of any particular locality and the deposit which is taking place at the bottom. In all seas, from the equator to the polar ice, the tow-net contains *Globigerinae*. They are more abundant, and of a larger size, in warmer seas; several varieties attaining a large size, and presenting marked varietal characters, are found in the inter-tropical area of the Atlantic. In the latitude of Kerguelen they are less numerous and smaller, while further south they are still more dwarfed, and only one variety, the typical *Globigerina bulloides*, is represented. The living *Globigerinae* from the tow-net are singularly different in appearance from the dead shells we find at the bottom (Plate I.). The shell is clear

* Die Radiolarien. Eine Monographie von Dr. Ernst Haeckel. Berlin, 1862, page 166-167.

† “Mr. Jeffreys desires to record his dissent from this conclusion, since (from his own observations, as well as those of Major Owen and Lieutenant Palmer) he believes *Globigerina* to be exclusively an *Oceanic* Foraminifer inhabiting only the superficial stratum of the sea.”—“Preliminary Report of the Scientific Exploration of the Deep Sea,” Proceedings of the Royal Society, No. 121, page 443.

and transparent, and each of the pores which penetrate it is surrounded by a raised crest, the crest round adjacent pores coalescing into a roughly hexagonal network, so that the pore appears to lie at the bottom of an hexagonal pit. At each angle of this hexagon the crest gives off a delicate flexible calcareous spine, which is sometimes four or five times the diameter of the shell in length. The spines radiate symmetrically from the direction of the centre of each chamber of the shell, and the sheaves of long transparent needles, crossing one another in different directions, have a very beautiful effect. The smaller inner chambers of the shell are entirely filled with an orange-yellow granular sarcode; and the large terminal chamber usually contains only a small irregular mass, or two or three small masses run together, of the same yellow sarcode stuck against one side, the remainder of the chamber being empty. No definite arrangement, and no approach to structure, was observed in the sarcode, and no differentiation, with the exception of round bright-yellow oil-globules, very much like those found in some of the Radiolarians, which are scattered apparently irregularly in the sarcode. We never have been able to detect the least trace of pseudopodia in any of the large number of *Globigerinae* which we have examined, nor any extension, in any form, of the sarcode beyond the shell.

Major Owen (*op. cit.*) has referred the *Globigerina* with spines to a distinct species, under the name of *G. hirsuta*. I am inclined rather to believe that all *Globigerinae* are, to a greater or less degree, spiny, when the shell has attained its full development. In specimens taken with the tow-net the spines are very usually absent; but that is probably on account of their extreme tenuity; they are broken off by the slightest touch. In fresh examples from the surface the dots indicating the origin of the lost spines may almost always be made out with a high power. There never are spines on the *Globigerinae* from the bottom, even in the shallowest water. Two or three very marked varieties of *Globigerina* occur; but I certainly do not think that the characters of any of them can be regarded as of specific value.

There is still a good deal of obscurity about the nature of *Orbulina universa*, an organism which occurs in some places in large proportion in the *Globigerina*-ooze. The shell of *Orbulina* (Pl. II.) is spherical, usually about .5 millimetre in diameter, but it is found of all smaller sizes. The texture of the mature shell resembles closely that of *Globigerina*, but it differs in some important particulars. The pores are markedly of two different sizes, the larger about four times the area of the smaller. The larger pores are the less numerous; they are scattered over the surface of the shell without any appearance of regularity; the smaller pores occupy the spaces between the larger. The crests between the pores are much less regular in *Orbulina* than they are in *Globigerina*; and the spines, which are of great length and extreme tenuity, seem rather to arise abruptly from the top of scattered papillæ than to mark the intersections of the crests.

This origin of the spines from the papillæ can be well seen with a moderate power on the periphery of the sphere. The spines are hollow and flexible; they naturally radiate regularly from the direction of the centre of the sphere; but in specimens which have been placed under the microscope with the greatest care, they are usually entangled together in twisted bundles. They are so fragile that the weight of the shell itself, rolling about with the motion of the ship, is usually sufficient to break off the whole of the spines and leave only the papillæ projecting from its surface, in the course of a few minutes. In some examples, either those in process of development, or a series showing a varietal divergence from the ordinary type, the shell is very thin and almost perfectly smooth, with neither papillæ nor spines, nor any visible structure, except the two classes of pores, which are constant.

The chamber of *Orbulina* is often almost empty; even in the case of examples from the surface, which appear, from the freshness and transparency of the shell, to be living, it is never full of sarcode; but it frequently contains a small quantity of yellow sarcode stuck against one side, as in the last chamber of *Globigerina*. Sometimes, but by no means constantly, within the chamber of *Orbulina* there is a little chain of three or four small chambers singularly resembling in form, in proportion, and in sculpture a small *Globigerina*; and sometimes, but again by no means constantly, spines are developed on the surface of the calcareous walls of these inner chambers, like those on the test of *Globigerina*. The spines radiate from the position of the centre of the chambers and abut against the insides of the wall of the *Orbulina* (Pl. II.). In a few cases, the inner chambers have been observed, apparently arising within or amidst the sarcode adhering to the wall of the *Orbulina*.

Major Owen regards *Orbulina* as a distinct organism, nearly allied to *Globigerina*, but differing so far from it as to justify its separation into a special subgenus. He considers the small inner chamber of *Orbulina* to represent the smaller chamber of *Globigerina*, and the outer wall as the equivalent of the large outer chamber of *Globigerina*, developed in this form as an investing chamber. Count Pourtales, Max-Schultze, and Krohn, on the other hand, believe, on account of the close resemblance in structure between the two shells, their constant association, and the undoubted fact that an object closely resembling a young *Globigerina* is often found within *Orbulina*, that the latter is simply a special reproductive chamber budded from the former, and capable of existing independently. I am rather inclined to the latter view, although I think much careful observation is still required to substantiate it; and some, even of our own, observations would seem to tell somewhat in the opposite direction. Although *Orbulina* and *Globigerina* are very usually associated, they are so in different proportions in different localities; and in the icy sea to the south of Kerguelen, although *Globigerina* was constantly taken in the surface-net, not a single *Orbulina* was detected. Like

Globigerina, *Orbulina* is most fully developed and most abundant in the warmer seas.

Associated with these forms, and, like them, living on the surface, and dead, with their shells in various stages of decay, at the bottom, there are two very marked species or varieties of *Pulvinulina*, *P. Menardii*, and *P. Micheliniana*. The general structure of *Pulvinulina* resembles that of *Globigerina*. The shell consists of a congeries of from five to eight chambers arranged in an irregular spiral. As in *Globigerina*, the last chamber is the largest; the inner smaller chambers are usually filled with yellow sarcode; and, as in *Globigerina*, the last chamber is frequently nearly empty, a small irregular mass of sarcode only occupying a part of the cavity. The walls of the chambers are closely and minutely perforated. The external surface of the wall is nearly smooth, and no trace of a spine has ever been detected. *Pulvinulina Menardii* (Pl. III. fig. 1) has a large discoidal depressed shell, consisting of a series of flat chambers overlapping one another, like a number of coins laid down somewhat irregularly, but generally in a spiral; each chamber is bordered by a distinct somewhat thickened solid rim of definite width. On the lower surface of the shell the intervals between the chambers are indicated by deep grooves. The large irregular opening of the final chamber is protected by a crescentic lip, which in some specimens bears a fringe of spine-like papillæ. This form is almost confined to the warmer seas. It is very abundant on the surface, and still more so during the day, at a depth of ten to twenty fathoms in the Mid-Atlantic; and it enters into the composition of the very characteristic "*Globigerina*-ooze" of the "Dolphine Rise" in almost as large proportions as *Globigerina*. *Pulvinulina Micheliniana* is a smaller variety; the upper surface of the shell is flattened as in *P. Menardii*, but the chambers are conical and prolonged downwards, so that the shell is deeper and somewhat turbinate. The two species usually occur together; but *P. Micheliniana* has apparently a much wider distribution than *P. Menardii*; for while the latter was limited to the region of the trade-winds and the equatorial drift current, and was found rarely if at all to the south of the Agulhas current, the former accompanied us southward as far as Kerguelen Land. Both forms of *Pulvinulina*, however, are more restricted than *Globigerina*; for even *P. Micheliniana* became scarce after leaving the Cape, and the wonderfully pure calcareous formation in the neighbourhood of Prince Edward Island and the Crozets consists almost solely of *Globigerina bulloides*, and neither species of *Pulvinulina* occurred to the south of Kerguelen Land.

Over a very large part of the "*Globigerina*-ooze" area, and especially in those intertropical regions in which the formation is most characteristically developed, although the great bulk of the ooze is made up of entire shells and fragments of shells of the above-described foraminifera, there is frequently a considerable proportion (amounting in

some cases to about twenty per cent.) of fine granular matter, which fills the shells and the interstices between them, and forms a kind of matrix or cement. This granular substance is, like the shells, calcareous, disappearing in weak acid to a small insoluble residue; with a low microscopic power it appears amorphous, and it is likely to be regarded, at first sight, as a paste made up of the ultimate calcareous particles of the disintegrated shells; but under a higher power it is found to consist almost entirely of "coccoliths" and "rhabdoliths." I need scarcely enter here into a detailed description of these singular bodies, which have already been carefully studied by Huxley, Sorby, Gümbel, Haeckel, Carter, Oscar Schmidt, Wallich, and others. I need only state that I believe our observations have placed it beyond a doubt that the "coccoliths" are the separated elements of a peculiar calcareous armature which covers certain spherical bodies (the "coccospheres" of Dr. Wallich). The rhabdoliths are the like elements of the armature of extremely beautiful little bodies, of which two forms are represented in Pl. III. figs. 3 & 4, which have been first observed by Mr. Murray and naturally called by him "rhabdospheres." Coccospheres and rhabdospheres live abundantly on the surface, especially in warmer seas. If a bucket of water be allowed to stand over night with a few pieces of thread in it, on examining the threads carefully many examples may usually be found attached to them; but Mr. Murray has found an unfailing supply of all forms in the stomachs of *Salpæ*.

What these coccospheres and rhabdospheres are, we are not yet in a position to say with certainty; but our strong impression is that they are either Algæ of a peculiar form, or the reproductive gemmules or the sporangia of some minute organism, probably an Alga; in which latter case the coccoliths and rhabdoliths might be regarded as representing in position and function the "amphidisci" on the surface of the gemmules of *Spongilla*, or the spiny facets on the zygospores of many of the Desmidiæ. There are many forms of coccoliths and rhabdoliths, and many of these are so distinct that they evidently indicate different species. Mr. Murray believes, however, that only one form is met with on one sphere; and that, in order to produce the numerous forms figured by Haeckel and Oscar Schmidt, all of which, and many additional varieties, he has observed, the spheres must vary in age and development, or in kind. Their constant presence in the surface-net, in surface-water drawn in a bucket, and in the stomachs of surface-animals, sufficiently proves that, like the ooze-forming Foraminifera, the coccoliths and rhabdoliths, which enter so largely into the composition of the recent deep-sea calcareous formations, live on the surface and at intermediate depths, and sink to the bottom after death. Coccospheres and rhabdospheres have a very wide, but not an unlimited, distribution. From the Cape of Good Hope they rapidly decreased in number on the surface and at the bottom, as we progressed southwards. The proportion of their remains in the *Globigerina*-ooze near the Crozets and Prince Edward Island was com-

paratively small; and to this circumstance the extreme clearness and the unusual appearance of being composed of *Globigerinae* alone was probably mainly due. We found the same kind of ooze, nearly free from coccoliths and rhabdoliths, in what may be considered about a corresponding latitude in the north, to the west of Farøe.

Before leaving the subject of the modern Chalk, it may be convenient to pass on to stations 158, 159, and 160, on March 7th, 10th, and 13th, on our return voyage from the ice. The first two of these, at depths of 1800 and 2150 fathoms respectively, are marked on the chart "*Globigerina*-ooze;" and it will be observed that these soundings nearly correspond in latitude with the like belt which we crossed going southwards; the third sounding, at a depth of 2600 fathoms, is marked "red clay."

According to our present experience, the deposit of "*Globigerina*-ooze" is limited to water of a certain depth, the extreme limit of the pure characteristic formation being placed at a depth of somewhere about 2250 fathoms. Crossing from these shallower regions occupied by the ooze into deeper soundings, we find universally that the calcareous formation gradually passes into, and is finally replaced by, an extremely fine pure clay, which occupies, speaking generally, all depths below 2500 fathoms, and consists, almost entirely, of a silicate of the red oxide of iron and alumina. The transition is very slow, and extends over several hundred fathoms of increasing depth; the shells gradually lose their sharpness of outline and assume a kind of "rotten" look and a brownish colour, and become more and more mixed with a fine amorphous red-brown powder, which increases steadily in proportion until the lime has almost entirely disappeared. This brown matter is in the finest possible state of subdivision, so fine that when, after sifting it to separate any organisms it might contain, we put it into jars to settle, it remained for days in suspension, giving the water very much the appearance and colour of chocolate.

In indicating the nature of the bottom on the charts, we came from experience, and without any theoretical consideration, to use three terms for soundings in deep water. Two of these, Gl. oz. and r. cl., were very definite, and indicated strongly marked formations, with apparently but few characters in common; but we frequently got soundings which we could not exactly call either "*Globigerina*-ooze" or "red clay;" and before we were fully aware of the nature of these we were in the habit of indicating them as "grey ooze" (gr. oz.). We now recognize the "grey ooze" as an intermediate stage between the *Globigerina*-ooze and the red clay; we find that, on one side as it were of an ideal line, the red clay contains more and more of the material of the calcareous ooze, while, on the other, the ooze is mixed with an increasing proportion of "red clay."

Although we have met with the same phenomenon so frequently, that we were at length able to predict the nature of the bottom from the

depth of the sound, with absolute certainty, for the Atlantic and the Southern Sea, we had perhaps the best opportunity of observing it in our first section across the Atlantic, between Teneriffe and St. Thomas. The first four stations on this section (Pl. IV.), at depths from 1525 to 2220 fathoms, show "*Globigerina*-ooze." From the last of these, which is about 300 miles from Teneriffe, the depth gradually increases to 2740 fathoms, at 500, and 2950 fathoms, at 750 miles from Teneriffe. The bottom in these two soundings might have been called "grey ooze;" for although its nature has altered entirely from the "*Globigerina*-ooze," the red clay into which it is rapidly passing still contains a considerable admixture of carbonate of lime.

The depth goes on increasing, to a distance of 1150 miles from Teneriffe, when it reaches 3150 fathoms; there the clay is pure and smooth, and contains scarcely a trace of lime. From this great depth the bottom gradually rises, and, with decreasing depth, the grey colour and the calcareous composition of the ooze return. Three soundings in 2050, 1900, and 1950 fathoms on the "Dolphin Rise," gave highly characteristic examples of the *Globigerina* formation. Passing from the middle plateau of the Atlantic into the western trough, with depths a little over 3000 fathoms, the red clay returns in all its purity: and our last sounding, in 1420 fathoms, before reaching Sombrero, restored the *Globigerina*-ooze with its peculiar associated fauna.

This section shows also the wide extension and the vast geological importance of the red-clay formation. The total distance from Teneriffe to Sombrero is about 2700 miles. Proceeding from east to west, we have

About 80 miles of volcanic mud and sand.

"	350	"	"	"	"	<i>Globigerina</i> -ooze,"
"	1050	"	"	"	"	" red clay,"
"	330	"	"	"	"	<i>Globigerina</i> -ooze,"
"	850	"	"	"	"	" red clay,"
"	40	"	"	"	"	<i>Globigerina</i> -ooze,"

giving a total of 1900 miles of red clay to 720 miles of *Globigerina*-ooze.

The following Table, taken from the chart, gives a good general idea of the distribution of the two formations with respect to depth. It cannot of course be taken as exact; the indications were jotted down from the impression of colour given at the time, and there is no hard and fast line between *Globigerina*-ooze and grey ooze on the one hand, and between red clay and grey ooze on the other. The Table gives an average depth of 1800 fathoms for our soundings in the *Globigerina*-ooze. This is a datum of no value; for we only rarely sounded in shallow water, and we know that this formation covers large areas at depths between 300 and 400 fathoms; but the mean maximum depth at which it occurs is important, and that may be taken from the Table as about 2250 fathoms. The mean depth at which we find the transition grey ooze is 2400 fathoms; and the mean depth of the red-clay soundings is

about 2700 fathoms. The general concurrence of so many observations would go far to prove, what seems now to stand, indeed, in the position of an ascertained fact, that wherever the depth increases from about 2200 to 2600 fathoms, the modern Chalk formation of the Atlantic and of other oceans passes into a clay.

No. of Station.	Nature of the Bottom.		
	Glob. Ooze.	Grey Ooze.	Red Clay.

From Cape Finisterre to Teneriffe.

I.	1125		
	1975		
II.	470		
	1800		
III.	1000		
VI.	1525		

From Teneriffe to St. Thomas.

1.	1890		
2.	1945		
4.	2220		
5.	..	..	2740
6.	..	..	2950
7.	..	..	2750
8.	..	..	2800
9.	..	..	3150
10.	..	..	2720
11.	..	..	2575
12.	2025		
13.	1900		
14.	1950		
15.	..	..	2325
16.	..	..	2435
17.	..	..	2385
18.	..	..	2675
19.	..	..	3000
20.	..	..	2975
21.	..	..	3025
22.	1420		
23.	450		

From St. Thomas to Bermudas.

25.	..	3875	
26.	..	2800	
27.	..	2960	
28.	..	..	2850
29.	..	..	2700
30.	..	..	2600
31.	..	2475	
32.	..	2250	
..	..	1820	

TABLE (*continued*).

No. of Station.	Nature of the Bottom.		
	Glob. Ooze.	Grey Ooze.	Red Clay.
From Bermudas to Halifax.			
37.	..	2650	
38.	..	2600	
39.	..	2850	
42.	..	2425	
44.	..	1700	
From Halifax to Bermudas.			
50.	..	1250	
51.	..	2200	
52.	..	2800	
53.	..	2650	
54.	..	2650	
55.	..	2500	
From Bermudas to the Azores.			
58.	..	1500	
59.	..	2360	
60.	..	2575	
61.	..	2850	
62.	..	2875	
63.	..	2750	
65.	..	2700	
66.	..	2750	
67.	..	2700	
68.	..	2175	
69.	..	2200	
70.	1675		
71.	1675		
72.	1240		
73.	1000		
74.	1350		
76.	900		
From the Azores to Madeira.			
78.	1000		
79.	2025		
80.	2660		
81.	2675		
82.	2400		
83.	1650		
From Madeira to Cape Verde Islands.			
86.	2300		
88.	2300		
89.	2400		
90.	2400		
91.	2075		
92.	1975		

TABLE (continued).

No. of Station.	Nature of the Bottom.		
	Glob. Ooze.	Grey Ooze.	Red Clay.
From the Cape Verde Islands to St. Paul Rocks.			
95.	2300		
97.	2575		
98.	1750		
102.	..	2450	
104.	..	2500	
105.	..	2275	
106.	1850		
107.	1500		
108.	1900		
From the St. Paul Rocks to S. Salvador.			
110.	2275		
111.	2475		
112.	2200		
5.	2150		
6.	2275		
From S. Salvador to Tristan d'Acunha.			
129.	..	..	2150
130.	..	..	2350
131.	2275		
132.	2050		
133.	1900		
134.	2025		
From Tristan d'Acunha to the Cape of Good Hope.			
137.	..	..	2550
138.	..	..	2650
139.	..	2325	
140.	..	1250	
From the Cape of Good Hope to Kerguelen Island.			
143.	1900		
144.	1570		
146.	1375		
147.	1600		
From Kerguelen Island to Melbourne.			
158.	1800		
159.	2150		
160.	..	..	2600

The nature and origin of this vast deposit of clay is a question of the very greatest interest; and although I think there can be no doubt that it is in the main solved, yet some matters of detail are still involved in

difficulty. My first impression was, that it might be the most minutely divided material, the ultimate sediment, produced by the disintegration of the land, by rivers and by the action of the sea on exposed coasts, and held in suspension and distributed by ocean currents, and only making itself manifest in places unoccupied by the *Globigerina*-ooze. Several circumstances seemed, however, to negative this mode of origin. The formation seemed too uniform; whenever we met with it, it had the same character, and it only varied in composition in containing less or more carbonate of lime.

Again, we were gradually becoming more and more convinced that all the important elements of the *Globigerina*-ooze lived on the surface; and it seemed evident that, so long as the conditions on the surface remained the same, no alteration of contour at the bottom could possibly prevent its accumulation; and the surface conditions in the Mid-Atlantic were very uniform, a moderate current of a very equal temperature passing continuously over elevations and depressions, and everywhere yielding to the tow-net the ooze-forming Foraminifera in the same proportion. The Mid-Atlantic swarms with pelagic Mollusca; and, in moderate depths, the shells of these are constantly mixed with the *Globigerina*-ooze, sometimes in number sufficient to make up a considerable portion of its bulk. It is clear that these shells must fall in equal numbers upon the red clay; but scarcely a trace of one of them is ever brought up by the dredge on the red-clay area. It might be possible to explain the absence of shell-secreting animals living on the bottom by the supposition that the nature of the deposit was injurious to them; but then the idea of a current sufficiently strong to sweep them away is negatived by the extreme fineness of the sediment which is being laid down; the absence of surface shells appears to be intelligible only on the supposition that they are in some way removed.

We conclude, therefore, that the "red clay" is not an additional substance introduced from without, and occupying certain depressed regions on account of some law regulating its deposition; but that it is produced by the removal, by some means or other, over these areas, of the carbonate of lime which forms probably about 98 per cent. of the material of the *Globigerina*-ooze. We can trace, indeed, every successive stage in the removal of the carbonate of lime in descending the slope of the ridge or plateau where the *Globigerina*-ooze is forming, to the region of the clay. We find, first, that the shells of pteropods and other surface Mollusca, which are constantly falling on the bottom, are absent, or if a few remain they are brittle and yellow, and evidently decaying rapidly. These shells of Mollusca decompose more easily, and disappear sooner, than the smaller and apparently more delicate shells of Rhizopods. The smaller Foraminifera now give way and are found in lessening proportion to the larger; the coccoliths first lose their thin outer border and then disappear, and the clubs of the rhabdoliths get worn out of shape and are last seen,

under a high power, as minute cylinders scattered over the field. The larger Foraminifera are attacked, and instead of being vividly white and delicately sculptured, they become brown and worn, and finally they break up, each according to its fashion; the chamber-walls of *Globigerina* fall into wedge-shaped pieces which quickly disappear, and a thick rough crust breaks away from the surface of *Orbulina*, leaving a thin inner sphere, at first beautifully transparent, but soon becoming opaque and crumbling away.

In the mean time, the proportion of the amorphous "red clay" to the calcareous elements of all kinds, increases, until the latter disappear, with the exception of a few scattered shells of the larger Foraminifera, which are still found, even in the most characteristic samples of the "red clay."

There seems to be no room left for doubt that the red clay is essentially the insoluble residue, the *ash*, as it were, of the calcareous organisms which form the *Globigerina*-ooze, after the calcareous matter has been by some means removed. An ordinary mixture of calcareous Foraminifera with the shells of Pteropods, forming a fair sample of "*Globigerina*-ooze" from near St. Thomas, was carefully washed and subjected by Mr. Buchanan to the action of weak acid; and he found that there remained, after the carbonate of lime had been removed, about one per cent. of a reddish mud, consisting of silica, alumina, and the red oxide of iron. This experiment has been frequently repeated with different samples of "*Globigerina*-ooze," and always with the result that a small proportion of a red sediment remains, which possesses all the characters of the "red clay."

In the *Globigerina*-ooze, siliceous bodies, including the spicules of Sponges, the spicules and tests of Radiolarians, and the frustules of Diatoms occur in appreciable proportion; and these also diminish in number, and the more delicate of them disappear in the transition from the calcareous ooze to the "red clay."

I have already alluded to the large quantity of nodules of the peroxide of manganese which were brought up by the trawl from the red-clay area on the 13th of March. Such nodules seem to occur universally in this formation. No manganese can be detected in the *Globigerina*-ooze; but no sooner has the removal of the carbonate of lime commenced than small black grains make their appearance, usually rounded and mammillated on the surface, miniatures, in fact, of the larger nodules which abound in the clay; and, at the same time, any large organic body, such as a shark's tooth, that may happen to be in the ooze is more or less completely replaced by manganese; and any inorganic body, such as a pebble or a piece of pumice, is coated with it, as a fine black mammillated layer. It is not easy to tell what the proportion of manganese in the red clay may be, but it is very considerable. At station 160, on the 13th of March, the trawl brought up nearly a bushel of nodules, from the size of a walnut to that of an orange; but these were probably the result of the sifting of a large quantity of the

clay. The manganese is doubtless, like the iron, set free by the decomposition of the organic bodies and tests. It is known to exist in the ash of some Algæ to the amount of 4 per cent.

The interesting question now arises as to the cause and method of the removal of the carbonate of lime from the cretaceous deposit; and on this matter we are not yet in a position to form any definite conclusion.

One possible explanation is sufficiently obvious. All sea-water contains a certain proportion of free carbonic acid, and Mr. Buchanan believes that he finds it rather in excess in bottom-water from great depths. At all events, the quantity present is sufficient to convert into a soluble compound, and thus remove a considerable amount of carbonate of lime. If the balance of supply be very delicately adjusted, it is just conceivable that the lime in the shells, in its fine state of subdivision, having been attacked by the sea-water from the moment of the death of the animal, may be entirely dissolved during its retarded passage through the half mile or so of water of increasing density. A great deal of the bottom-water in these deep troughs has been last at the surface, in the form of circumpolar freshwater ice; and though fully charged with carbonic acid, it is possible that it may be comparatively free from carbonate of lime, and that its solvent power may thus be greater.

The red clay or, more probably, the circumstances which lead to its deposition seem on the whole unfavourable to the development of animal life. Where its special characters are most marked, no animals which require much carbonate of lime for the development of their tissues or of their habitations appear to exist. Our growing experience is, that although animal life is possible at all depths, after a certain depth, say 1500 fathoms, its abundance diminishes. This would seem to indicate that the extreme conditions of vast depths are not favourable to its development; and one might well imagine that the number of shell-building animals might decrease, until the supply of lime was so far reduced as to make it difficult for them to hold their own against the solvent power of the water of the sea—just as in many districts where there is little lime, the shells of land and freshwater mollusks are light and thin, and the animals themselves are stunted and scarce.

It seems, however, that neither the extreme depth at which the red clay is found, nor the conditions under which it is separated and laid down, are sufficient entirely to negative the existence of living animals, even of the higher invertebrate orders. In several of the hauls, we brought up Holothurids of considerable size, with the calcareous neck-rings very rudimentary, and either no calcareous bodies in the test, or a mere trace of such. Nearly every haul gave us delicate branching Bryozoa, with the zooëcium almost membranous. One fortunate cast, about 150 miles from Sombbrero, brought up, from a depth of 2975 fathoms, very well-marked red mud, which did not effervesce with hydrochloric acid. Entangled in the dredge, and imbedded in the mud, were many of

the tubes of a tube-building annelid, several of them 3 to 4 inches long, and containing the worm, a species of *Myriochele*, still living. The worm-tubes, like all the tests of Foraminifera from the same dredging, were made up of particles of the red clay alone.

It seems evident, from the observations here recorded, that *clay*, which we have hitherto looked upon as essentially the product of the disintegration of older rocks, under certain circumstances, may be an organic formation like chalk; that, as a matter of fact, an area on the surface of the globe, which we have shown to be of vast extent, although we are still far from having ascertained its limits, is being covered by such a deposit at the present day.

It is impossible to avoid associating such a formation with the fine, smooth, homogeneous clays and schists, poor in fossils, but showing worm-tubes and tracks, and bunches of doubtful branching things, such as *Oldhamia*, siliceous sponges, and thin-shelled peculiar shrimps. Such formations, more or less metamorphosed, are very familiar, especially to the student of palæozoic geology, and they often attain a vast thickness. One is inclined, from this great resemblance between them in composition and in the general character of the included fauna, to suspect that these may be organic formations, like the modern red clay of the Atlantic and Southern Sea, accumulations of the insoluble ashes of shelled creatures.

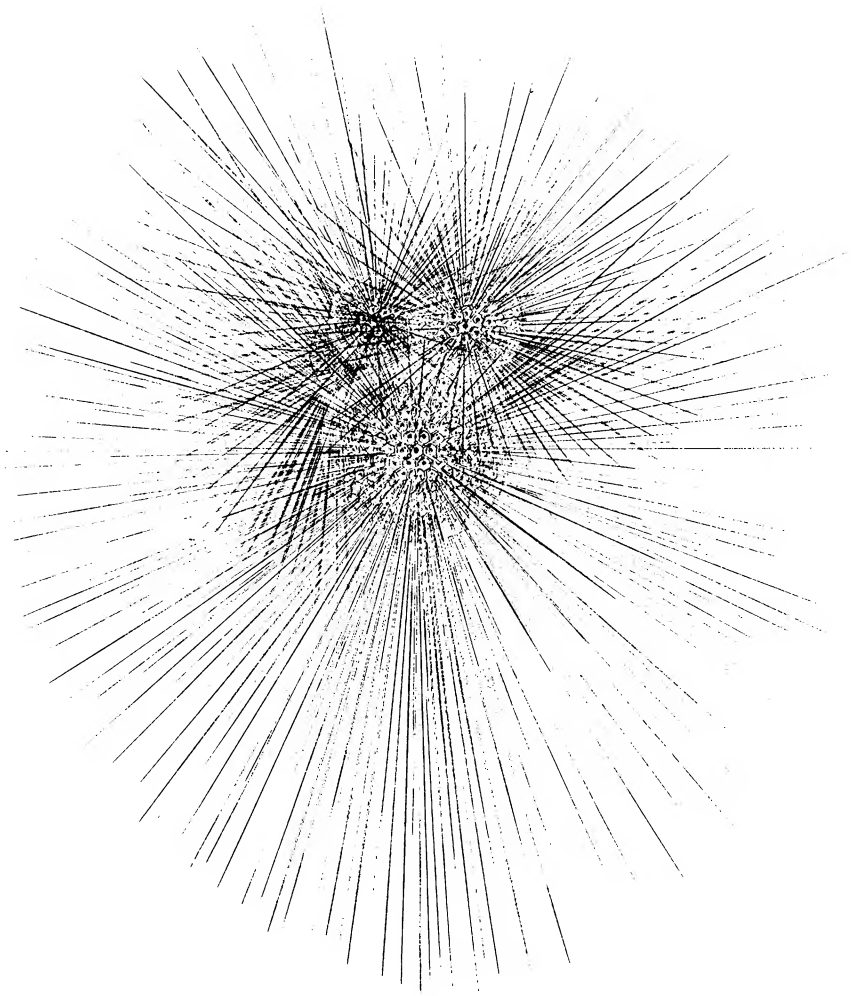
The dredging in the red clay on the 13th of March was unusually rich. The bag contained examples, those with calcareous shells rather stunted, of most of the characteristic deep-water groups of the Southern Sea, including *Umbellularia*, *Euplectella*, *Pterocrinus*, *Brisinga*, *Ophioglypha*, *Pourtalesia*, and one or two Mollusca. This is, however, very rarely the case. Generally the "red clay" is barren, or contains only a very small number of forms.

On the 11th of February, lat. 60° 52' S., long. 80° 20' E., and March 3, lat. 53° 55' S., long. 108° 35' E., the sounding-instrument came up filled with a very fine cream-coloured paste, which scarcely effervesced with acid, and dried into a very light impalpable white powder. This, when examined under the microscope, was found to consist almost entirely of the frustules of Diatoms, some of them wonderfully perfect in all the details of their ornament, and many of them broken up. The species of diatoms entering into this deposit have not yet been worked up, but they appear to be referable chiefly to the genera *Fragillaria*, *Coscinodiscus*, *Chaetoceros*, *Asteromphalus*, and *Dictyocha*, with fragments of the separated rods of a singular siliceous organism, with which we were unacquainted, and which made up a large proportion of the finer matter of this deposit. Mixed with the Diatoms there were a few small *Globigerinæ*, some of the tests and spicules of Radiolarians, and some sand particles; but these foreign bodies were in too small proportion to affect the formation as consisting practically of diatoms alone. On the 4th of February, in lat. 52° 29' S., long. 71° 36' E., a little to the north of the

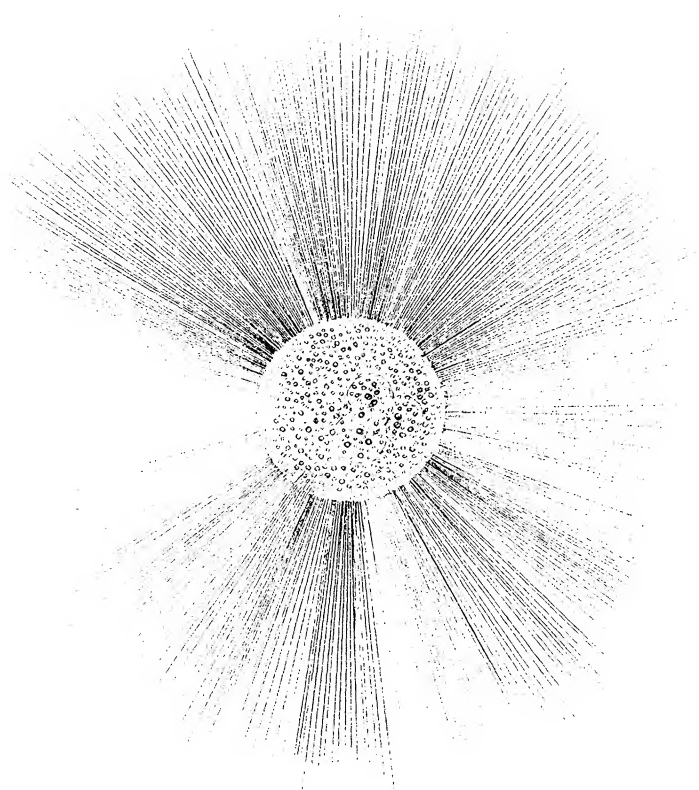
Heard Islands, the tow net, dragging a few fathoms below the surface, came up nearly filled with a pale yellow gelatinous mass. This was found to consist entirely of Diatoms of the same species as that found at the bottom. By far the most abundant was the little bundle of siliceous rods (Pl. III. fig. 5) fastened together loosely at one end, separating from one another at the other end, and the whole bundle loosely twisted into a spindle. The rods are hollow, and contain the characteristic endochrome of the *Diatomaceæ*. Like the "*Globigerina*-ooze," then, which it succeeds to the southward in a band apparently of no great width, the materials of this siliceous deposit are derived entirely from the surface and intermediate depths. It is somewhat singular that Diatoms did not appear to be in such large numbers on the surface over the Diatom-ooze as they were a little further north. This may perhaps be accounted for by our not having struck their belt of depth with the tow-net; or it is possible that when we found it, on the 11th of February, the bottom deposit was really shifted a little to the south by the warm current, the excessively fine flocculent *débris* of the Diatoms taking a certain time to sink. The belt of Diatom-ooze is certainly a little further to the southward in long. 80° E. in the path of the reflux of the Agulhas current, than in long. 108° E.

All along the edge of the ice pack—everywhere in fact to the south of the two stations, that of the 11th of February, on our southward voyage, and that of the 3rd of March, on our return, we brought up fine sand and greyish mud, with small pebbles of quartz and felspar, and small fragments of mica-slate, chlorite-slate, clay-slate, gneiss, and granite. This deposit, I have no doubt, was derived from the surface like the others, but, in this case, by the melting of icebergs and the precipitation of foreign matter contained in the ice.

We never saw any trace of gravel or sand, or any material necessarily derived from land, on an iceberg. Several showed vertical or irregular fissures filled with discoloured ice or snow; but, when looked at closely, the discoloration proved usually to be very slight, and the effect, at a distance, was usually due to the foreign material which filled the fissure reflecting light less perfectly than the general surface of the berg. I conceive that the upper part of one of these great tabular southern icebergs, including by far the greater part of its bulk, and culminating in the portion exposed above the surface of the sea, was formed by the piling up of successive layers of snow throughout the period, amounting perhaps to several centuries, during which the ice-cap was slowly forcing itself over the low land and out to sea, over a long extent of gentle slope, until it reached a depth considerably above 200 fathoms, when the lower specific weight of the ice caused an upward strain, which at length overcame the cohesion of the mass, and portions were rent off and floated away. If this be the true history of the formation of these icebergs, the absence of all land *débris* in the portion exposed above the surface of the



GL. OTTIGERINA.



ORBULINA.

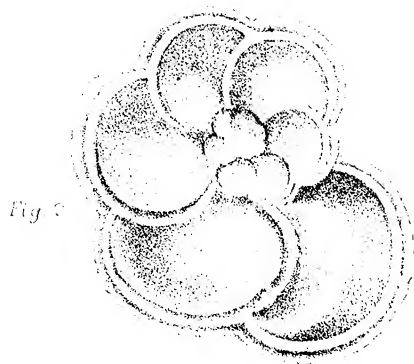


Fig. 2.

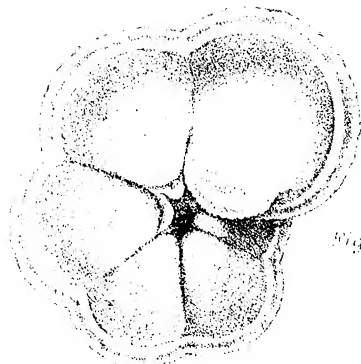


Fig. 1.

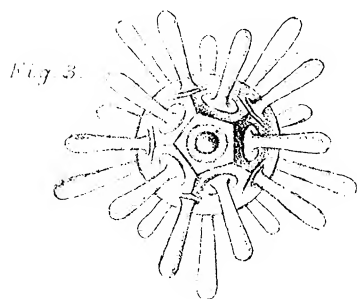


Fig. 3.

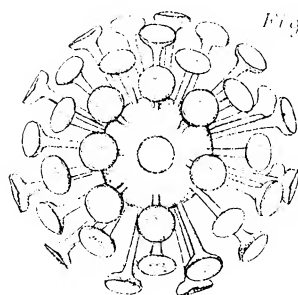


Fig. 4.

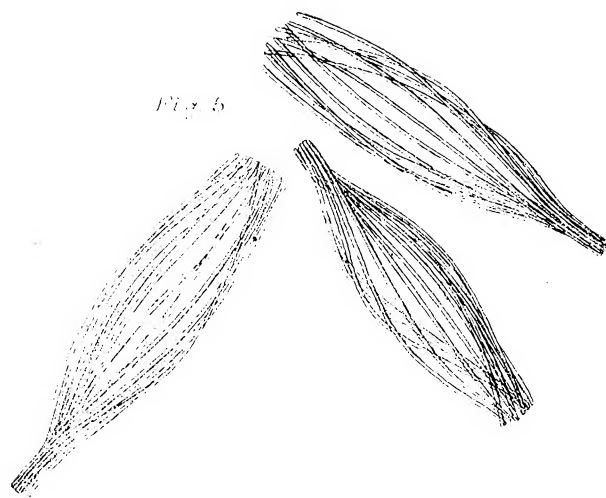
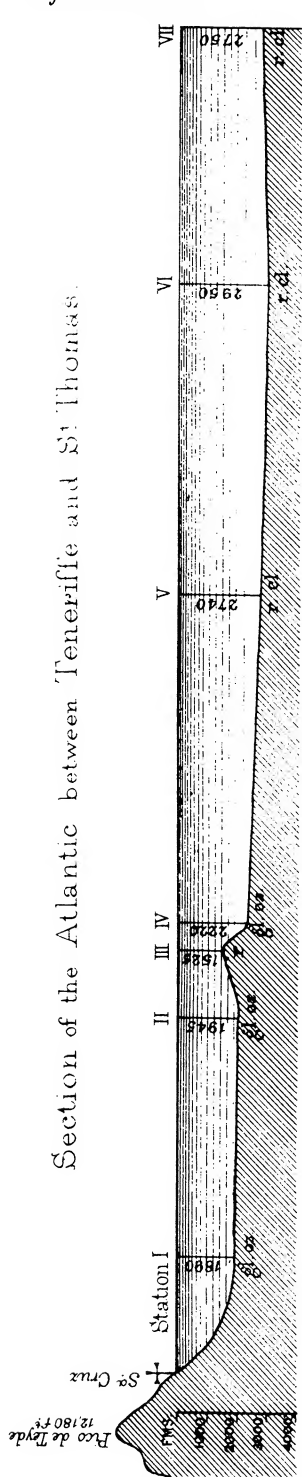


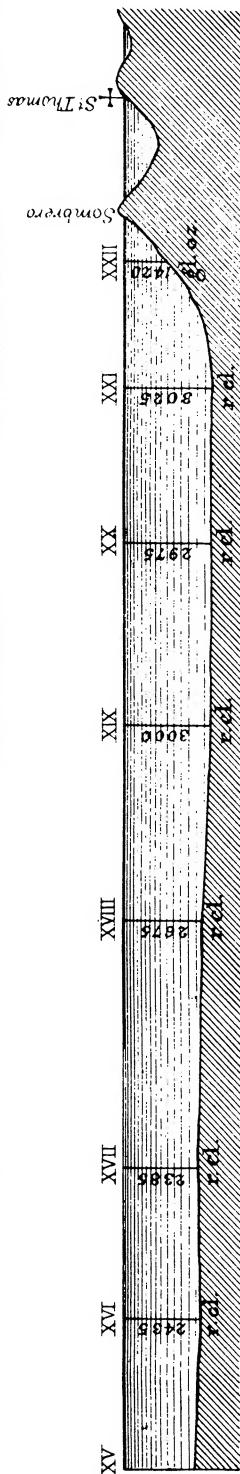
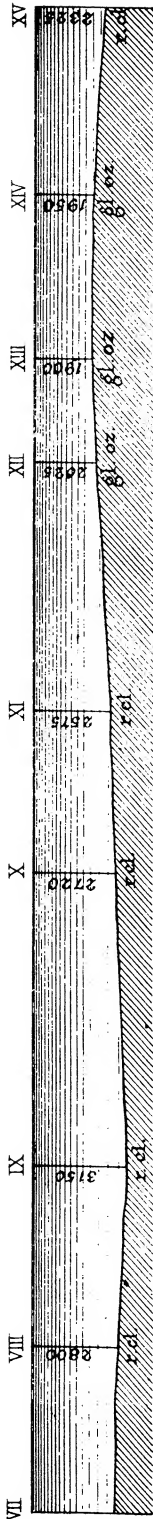
Fig. 5.

Figs 1 & 2. *Pulvinulina*. Figs 3 & 4. *Rhabdoliths*.
Fig. 5. *Diatoms*.

Section of the Atlantic between Tenerife and St. Thomas.



W. H. Miller, del.



Scale 20 mm = 100 naut. miles.



W. West & Co. imp.

sea is readily understood. If any such exist it must be confined to the lower part of the berg, to that part which has, at one time or other, moved on the floor of the ice-cap.

The icebergs, when they are first dispersed, float in from 200 to 250 fathoms. When, therefore, they have been drifted to latitudes of 65° or 64° S., the bottom of the berg just reaches the layer at which the temperature of the water is distinctly rising; and it is rapidly melted, the mud and pebbles with which it is more or less charged being precipitated to the bottom. That this precipitation takes place all over the area where the icebergs are breaking up constantly, and to a considerable extent, is evident from the fact of the soundings being entirely composed of such deposits; for the Diatoms, *Globigerina*, and Radiolarians are present on the surface in large numbers; and unless the deposit from the ice were abundant it would soon be covered and masked by a layer of the exuvia of surface-organisms.

EXPLANATION OF THE PLATES.

PLATES I. & II.

A *Globigerina* and an *Orbulina*, with the radiating processes entire.

PLATE III.

Figs. 1 & 2. *Pulvinulina*. Figs. 3 & 4. Rhabdoliths. Fig. 5. The new Diatom.

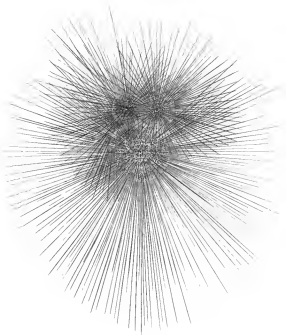
November 30, 1874.

ANNIVERSARY MEETING.

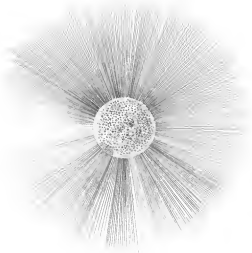
WILLIAM SPOTTISWOODE, M.A., Treasurer and Vice-President, in the Chair.

General Boileau, for the Auditors of the Treasurer's Accounts on the part of the Society, reported that the total receipts during the past year, including a balance of £693 13s. 5d. carried from the preceding year, amount to £5726 3s. 3d.; and that the total expenditure in the same period amounts to £5451 11s. 5d., leaving a balance at the Bankers of £236 18s. 8d., and £37 13s. 2d. in the hands of the Treasurer.

The thanks of the Society were voted to the Treasurer and Auditors.



GLOBIGERINA



ORBULINA.



Fig. 1

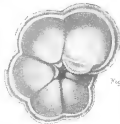


Fig. 2

Fig. 3



Fig. 4



Fig. 5



Fig. 1 & 2 Pulvinulina. Fig. 3 & 4 Rhabdoulithes.
Fig. 5 Diatoms

Section of the Atlantic between Teneriffe and S' Thomas

